AlN THIN FILM UNIMORPH PIEZOELECTRIC ACTUATORS ON POLYSILICON MICROBRIDGES

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Abstract - We present a surface micromachining process to fabricate AlN piezoelectric microstructures. The fabrication process utilizes SiO_2 sacrificial layer etching with polysilicon as a structural layer. The significance of the process is that the polysilicon layer is used as a structural as well as a bottom electrode layer. A thin layer of Cr is used as a mask layer to etch both the AlN and polysilicon layers, while acting as a top electrode. The fabricated clamped-clamped beam microbridges show compressive stress. Preliminary results using phase-shift interferometry measurements show displacements of 8.3 nm/V on a typical microbridge with dimensions 385 x 50 μm.

Key Words: *Aluminum nitride, Piezoelectric actuator, RF reactive sputtering, Phase-shift interferometry*

I. INTRODUCTION

In recent years, aluminum nitride (AlN) thin films have received considerable interest as promising candidates for a variety of applications: electrically insulating material, thermal conductor, dielectric and passivation layers, surface acoustic wave (SAW) devices and photoelectric devices [1-3]. Integration of AlN thin films in surface micromachining processes finds applications as thin film resonators and filters [4, 5]. Many techniques, such as DC/RF sputtering [6, 7], chemical vapor deposition (CVD) [8], laser chemical vapor deposition (LCVD) [9], pulsed laser ablation (PLD) and molecular beam epitaxy (MBE) [10], have been used for AlN thin film deposition on various substrates. Integration of the AlN thin film in surface micromachining process requires specific processes with a suitable combination of electrodes and structural layer. In this work, RF reactive sputtering is used to grow preferred oriented (002) AlN thin films on a polysilicon layer. The properties of the AlN thin films are greatly influenced by its microstructure, which is strongly affected by the deposition conditions.

In this paper, we report a surface micromachining process with polysilicon as both electrode and structural material to fabricate AlN unimorph piezoelectric micro actuators. A stack of Cr/AlN/polysilicon^{++} forms a unimorph piezoelectric actuator configuration. Phase-shift interferometry (PSI) has been used to measure the deflection of the unimorph microactuator as a function of applied voltage.

II. MICROFABRICATION PROCESS

The microfabrication process involves the sacrificial oxide layer etching to release the microstructures such as cantilevers and suspended beams or microbridges. A highly doped silicon wafer is used as a substrate to have good electrical conductivity for probing. A Nordiko-2000 multi target sputter system is used for the deposition of AlN thin films on doped polysilicon layer using optimised sputter parameters as shown in table 1. A thin layer of Cr is also deposited on the AlN layers, without breaking vacuum to ensure sufficient adhesion of Cr with the AlN layer. The Cr layer is used as a mask for patterning AlN and polysilicon layers.

Table 1. AlN deposition conditions

Parameters	Values
Base pressure (mbar)	$< 3 \times 10^{-7}$
Substrate layer	Poly++/SiO_2/Si
Sputter pressure (mbar)	3.3×10^{-3}
RF power (W)	350
Ar:N_2 flow rate (sccm)	8:3
Substrate temperature (^{0}C)	360
Target-substrate distance (cm)	6

The process flow schematic is shown in figure 1. Two masks are required: a sacrificial etching mask and a top electrode patterning mask. The process starts with a highly doped p-type Si (100) substrate with a sacrificial layer (wet oxidized SiO_2) to a thickness of 3 μm. The sacrificial etch mask is used to pattern the oxide layer.

solid-source diffusion at 1050° C to achieve better electrical conductivity. This is followed by a single-run deposition of a Cr/AlN layer stack on polysilicon. The thicknesses of the AlN and the Cr layers are 0.8 μm and 0.1 μm respectively. Then, microstructure pattern transfer is done using a top electrode mask, which defines the active microstructure area. The Cr layer is patterned first and then the AlN thin film is etched anisotropically using TMAH 25 % solution at room temperature. The polysilicon layer is etched by using Bosch's directional etching. Thus, the whole microstructure pattern is transformed into a stack of Cr/AlN/polysilicon layers with a single mask. This process facilitated to make etch openings to etch the sacrificial layer and to release the microstructures. Typical scanning electron microscopic (SEM) pictures of released microstructures are shown in figures 2 and 3.

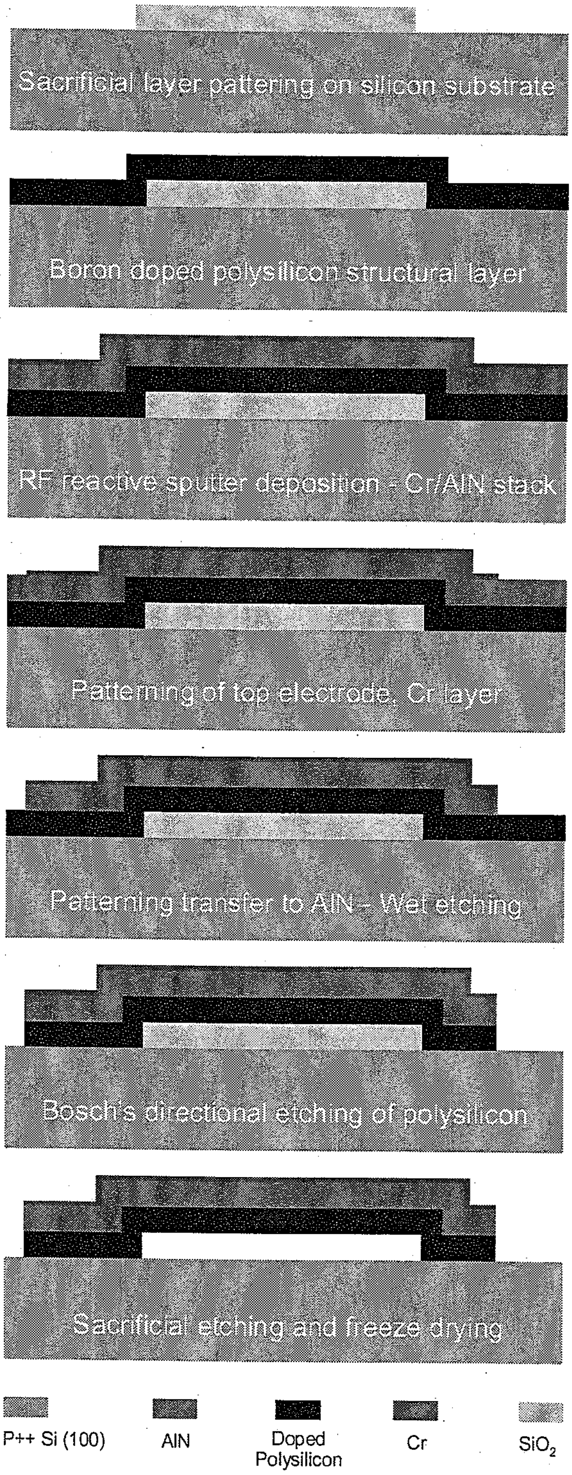

Fig. 1. Schematic surface micromachining process for the fabrication of AlN thin film unimorph microstructures.

An LPCVD polysilicon structural layer, to a thickness of 1.8 μm is then deposited. Subsequently, it is doped with boron dopant by

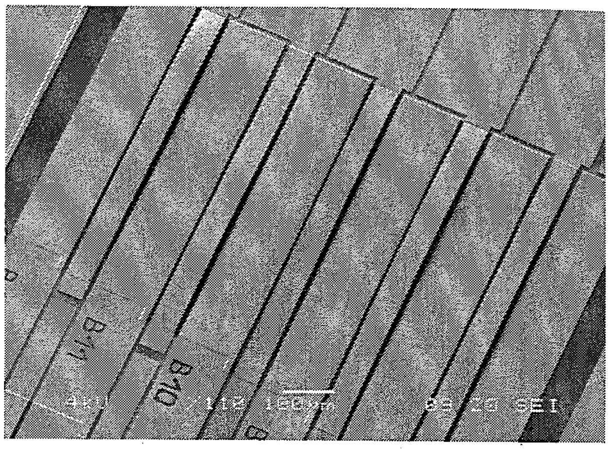

Fig. 2. SEM image of piezoelectric AlN microbridges with compressive stress.

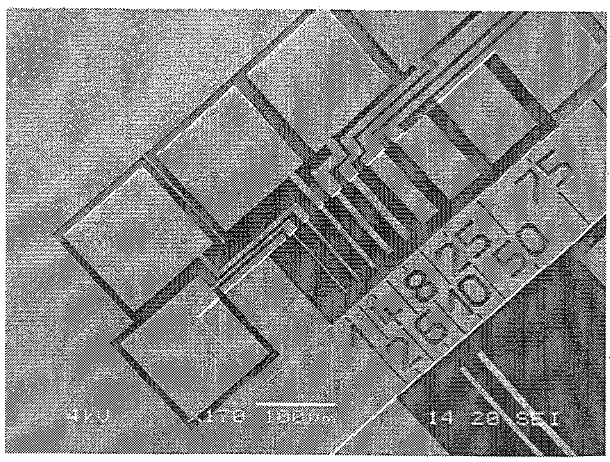

Fig. 3. SEM image of AlN thin film cantilevers with size down to 2 μm.

The minimum feature size of the microstructures is 2 μm as shown in figure 3. The microbridges, clamped at both ends, show compressive stress. This is mainly due the presence of residual stress in the AlN thin film during the deposition process.

III. PIEZOELECTRIC ACTUATION AND INTERFEROMETRY

A Leitz interference microscope has been used for displacement measurement of the microbridges. The out-of-plane displacement is measured with 3-5 nm accuracy by making use of the PSI [11]. The schematic measurement setup is shown in figure 4. A green LED with a wavelength of 535 nm is used as a light source for the microscope in combination with a green filter. Using a beam splitter and an adjustable mirror an interferogram is obtained on a CCD camera. A piezo stack is used to move the stage linearly in z-direction for scanning fringes over the Device Under Test (DUT). The CCD camera is used to capture moving fringe patterns for every voltage applied to the DUT. Preliminary measurements have been done on one of the microbridges as shown in figure 2 with dimensions 385 x 50 μm. For piezoelectric actuation, dc voltages between -10 V to +10 V have been applied in steps.

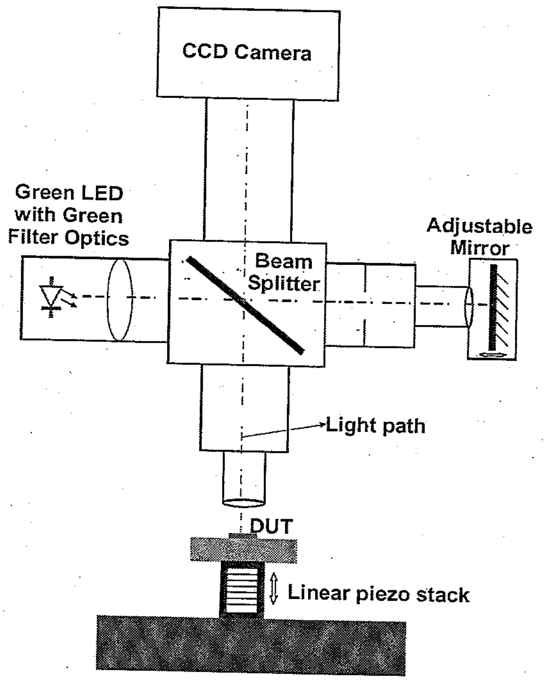

Fig. 4. Schematic diagram of an experimental setup with Leitz interference microscope.

In order to determine the bending of the microbridge, the optical phase difference between pixels is calculated by applying a Fast Fourier Transform (FFT) on the fringe patterns. Then using a phase unwrapping algorithm, the bending profile of the microbridges is reconstructed as shown in figure 5. To calculate the piezo-induced deflection, two surface profiles are subtracted to find the deflection for a given voltage. The results are shown in figures 6 and 7.

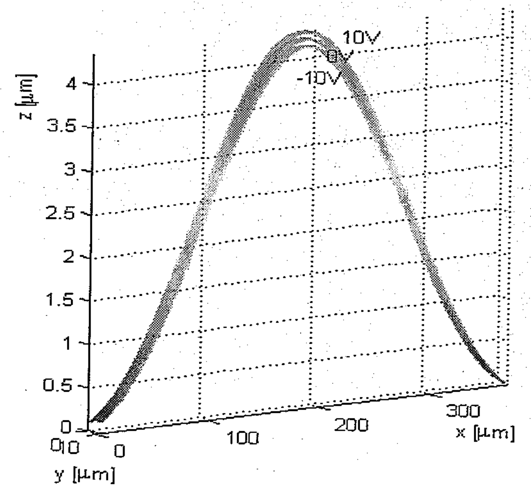

Fig. 5. Bending profiles of a microbridge for various dc voltages, 10, 0 and -10 V respectively.

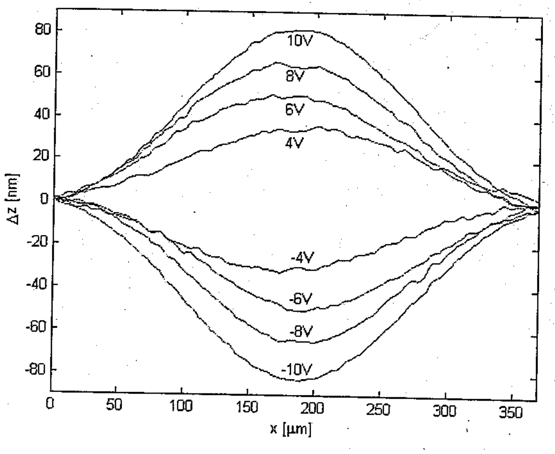

Fig. 6. Deflection profiles of a microbridge for various voltages from +10 V to -10 V.

The microbridge shows a symmetric bending curvature from its equilibrium position, 0 V for applied voltages between ± 10 V. For positive voltages, the microbridge deflects to the positive z-direction from its equilibrium position and vice-versa as shown in figure 5. The deflection measured is found to be linear with applied voltage. The sensitivity of the microbridge is determined by linear curve fitting as shown in figure 7 and it is found to be 8.29 nm/V.

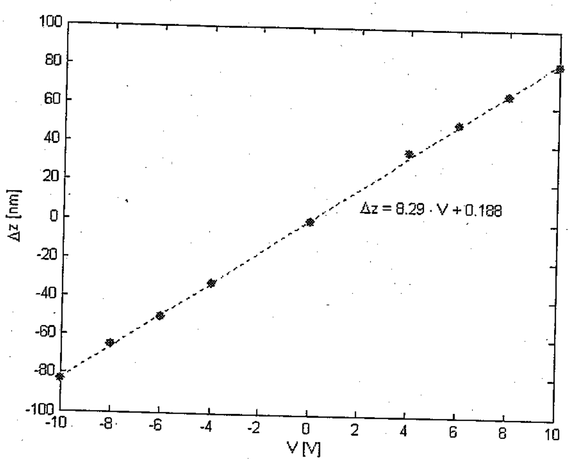

Fig. 7. Linear piezoelectric response (sensitivity ~ 8.3 nm/V) of a microbridge for applied DC voltages.

V. CONCLUSIONS

In conclusion, an integrated surface micromachining process for AlN thin films is reported. The polysilicon layer is used as both electrode and structural layer for AlN unimorph piezoelectric microstructures. IT is also shown that the sufficient adhesion of Cr to AlN to allow the Cr to be used as an etch mask for the AlN. The fabricated microbridges show compressive stress. Preliminary piezoelectric actuation on an AlN unimorph microbridge has been demonstrated using phase-shift interferometry measurements. A linear piezoelectric effect is observed with a deflection sensitivity of 8.3 nm/V and it shows the successful integration of AlN into the surface micromachining process. Dynamic characterization of the microbridges are in progress.

REFERENCES

[1] A. Kumar, H.L. Chan, J.J. Weimer, L. Sanderson, Structural characterization of pulsed laser-deposited AlN thin films on semiconductor substrates, *Thin Solid Films*, **Vol. 308-309**, pp. 406–409, 1997.

[2] A. Giardini, A. Mele, T.M. DiPalma, C. Flamini, S. Orlando, R. Teghil, AlN thin film deposition by pulsed laser ablation of Al in NH_3, *Thin Solid Films*, **Vol. 295**, pp. 77–82, 1997.

[3] N. Tanaka, H. Okano, T. Usuki, K. Shibata, Preparation of Aluminum Nitride Epitaxial Films by Electron Cyclotron Resonance Dual-Ion-Beam Sputtering, *Jpn. J. Appl. Phys.*, Vol. 33, pp 5249–5254, 1994.

[4] H. H. Kim, B. K. Ju, Y. H. Lee, S. H. Lee, J. K. Lee, S. W. Kim, A noble suspended type thin film resonator (STFR) using the SOI technology, *Sensors and actuators A*, **Vol. 89**, pp. 255-258, 2001.

[5] M. Hara, Jan Kuypers, Takashi Abe, Masayoshi Esashi, Surface micromachined AlN thin film 2 GHz resonators for CMOS integration, *Sensors and actuators A*, **Vol. 117**, pp. 211-216, 2005.

[6] S. Muhl, J.A. Zapien, J.M. Mendez, E. Andrade, Aluminium nitride films prepared by reactive magnetron sputtering, *J. Phys. D: Appl. Phys.*, **Vol. 30**, pp. 2147–2155. 1997.

[7] G. Carlotti, G. Gbbiotti, F.S. Hickernell, H.M. Liaw, G. Socino, Comparative study of the elastic properties of polycrystalline aluminum nitride films on silicon by Brillouin light scattering, *Thin Solid Films*, **Vol. 310**, pp. 34–38, 1997.

[8] A.V. Dobrynin, Thermoelastic strain and plastic yielding in aluminum nitride on sapphire, *J. Appl. Phys.*, **Vol. 85**, pp. 1876–1882, 1999.

[9] G. Radhakrishnan, Properties of AlN films grown at 350 K by gas-phase excimer laser photolysis, *J. Appl. Phys.* **Vol. 78**, pp. 6000–6005, 1995.

[10] S. Tanaka, R.S. Kern, J. Bentley, R.F. Davis, Defect Formation during Hetero-Epitaxial Growth of Aluminum Nitride Thin Films on 6H-Silicon Carbide by Gas-Source Molecular Beam Epitaxy, *Jpn. J. Appl. Phys.*, **Vol. 350**, pp. 1641–1647, 1996.

[11] S H Wang, C J Tay, C Quan and H M Shang, Determination of deflection and Youngs's modulus of a micro-beam by means of interferometry, *Meas. Sci. Technol.*, **Vol. 12**, pp. 1279-1286, 2001.